SUBSCRIBER LINE INTERFACE CIRCUIT (SLIC) INCLUDING A TRANSIENT OUTPUT CURRENT LIMIT CIRCUIT AND RELATED METHOD

Related Application

The present application is based upon co-pending provisional application serial no. 60/262,900 filed January 19, 2001, which is hereby incorporated herein in its entirety by reference.

Field of the Invention

The present invention relates to the field of electronic circuits, and, more particularly, to subscriber line interface circuits (SLICs).

Background of the Invention

A telephone network typically includes numerous switch offices which may be connected together via transmission lines, wireless links, etc. Central switching offices are connected to individual local telephone subscribers by subscriber loops. Each loop includes tip and ring wires carrying signals from the switch office to the telephone and from the telephone to the central office. A subscriber line interface circuit (SLIC) is typically used as the primary interface between the subscriber loop and the central office. Among other functions, the SLIC provides a direct current (DC) voltage from a battery source to

the subscriber loop when the phone is on-hook. This DC voltage is used to detect when the subscriber telephone is off-hook as well as provide power to the circuits within the telephone itself. When the subscriber is on-hook, this voltage ranges from -42V to -60V, but is typically -48V.

The resistance of the subscriber loop increases with the distance the telephone is located from the switch office. This may cause excessive current to flow on shorter subscriber loops, particularly transient currents which occur when the telephone first goes off-hook and during ringing and loop start. This may have undesirable effects on power supplies, particularly in wireless local loop (WLL) and digitally added main line (DAML) applications where the SLIC circuit is located on the subscriber's premises rather than at the switch office (i.e., the subscriber loop is very short).

One prior art method of limiting current is to sense current with a resistor and bipolar transistor connected together. The voltage applied to the base-emitter junction of the transistor is proportional to the current through the resistor. The collector terminal is typically connected to a current drive source that drives the current buffer to provide negative feedback when the transistor is turned on due to the current through the resistor. This style of current limiting is often used in the output stage of operational amplifiers. Class A style amplifiers use a single limiter circuit, while Class B and Class AB amplifiers often use a complementary pair of limiter circuits, as will be understood by those of skill in the art.

There are several drawbacks to current limiting an op amp when it is constructed as an

integrated circuit. The first is temperature variation. In an integrated circuit, resistors and transistors often have opposite temperature coefficients, causing large variations over the temperature range over which the circuit is used. The second drawback is the variation caused by unrelated process variations. The materials used to construct the transistor are often unrelated to that of the resistor, again causing large variations in the limit current of the circuit. The third drawback to this style of the circuit is the loss of dynamic range of the op amp. Since the circuit is in series with the output driver transistors, the voltage drop caused by the resistor reduces the voltage range capability to drive signals to a load.

Another prior art device disclosed in U.S. Patent No. 4,771,228 to Hester et al. entitled "Output Stage Current Limit Circuit" uses a scaled version of the output current to drive the resistor in the circuit mentioned above. This current limit circuit splits the output current into two components and uses one of them to sense the value of the output current. This portion of the output current can be accurately split using the mirroring effect of like transistors, and has the added advantage of not reducing the dynamic range of the amplifier. In this configuration, the current that is split is used to drive a resistor and transistor in the same manner as in the above circuit. Yet, this current limit circuit may also suffer from variations due to temperature and process parameters.

Still another prior art approach to limiting current on a subscriber loop is disclosed in U.S. Patent No. 4,485,341 to Welty et al. entitled "Current Limiter Circuit." This patent discloses a circuit for limiting the magnitude of current sourced from a first

load circuit to a second load circuit to a predetermined value. The circuit includes a current sourcing circuit for sourcing current from the first load circuit to the second and a feedback circuit which is responsive to the magnitude of the current sourced to the second load circuit reaching the predetermined value. The feedback circuit supplies any additional current that the second load may require while inhibiting additional current from being sourced from the first load.

One limitation of SLICs including such prior art current limiters is that it may be relatively difficult to use such SLICs for multiple applications due to the varying currents that may be present in such applications. For example, the off-hook DC voltage applied to a subscriber loop typically varies from about -24V to -100V depending upon the application and the status of the subscriber loop. Further, greater ringer equivalent numbers (REN) may be needed in certain applications, resulting in a corresponding decrease in resistance. As such, DC voiceband currents, ring trip currents, etc. may vary widely depending upon the application. Thus, a single prior art SLIC may not be easily interchangeable between multiple applications since there may be no ready way to adjust the current thresholds for the given application.

Another limitation of such prior art current limiting devices is that they do not allow for both sourcing and sinking of current. As a result, such circuits may not allow the system to reach a steady state quick enough to adequately protect against extreme transient events, such as a short circuit ground fault or battery fault condition.

Summary of the Invention

In view of the foregoing background, it is therefore an object of the invention to provide a SLIC including a transient current limit circuit that has relatively easily programmable current limits and provides for current sourcing and sinking.

This and other objects, features, and advantages in accordance with the present invention are provided by a SLIC including a pair of output amplifiers for connection to the subscriber loop and a transient output current limit circuit. The transient output current limit circuit may have at least one programmable output current limit, and limit respective output currents from the pair of output amplifiers based thereon.

More particularly, the transient output current limit circuit may limit both source and sink currents for each of the pair of output amplifiers. Further, the transient output current limit circuit may generate a source current limit and a sink current limit based upon the at least one programmable current limit. The sink current limit may be offset a predetermined amount higher than the source current limit, e.g., 40% higher than the source current limit. Alternatively, the at least one programmable output current limit may include a programmable sink current limit and a programmable source current limit.

The transient output current limit circuit may include a reference current generator for generating a reference current based upon the at least one programmable output current limit. The transient output current limit circuit may also include source and sink comparators for comparing sensed source and sink output currents for each of the output amplifiers with the reference current. Furthermore, respective

source and sink prescalers may be connected to the source and sink comparators. Additionally, the transient output current limit circuit may further include at least one transconductance stage connected between the source and sink comparators and the pair of output amplifiers.

The at least one programmable output current limit may be programmed by connecting a programming resistor between a reference voltage and the reference current generator. Also, the reference current generator may include a temperature stabilized voltage reference source. The SLIC may further include a direct current (DC) loop current limit circuit for limiting current on the subscriber loop to a DC current limit. Moreover, the at least one programmable output current limit may be higher than the DC current limit. For example, the at least one programmable output current limit may be less than about 50% higher than the DC current limit

A method aspect of the invention is for limiting current on a subscriber loop. The method may include connecting a pair of output amplifiers to the subscriber loop, programming at least one output current limit, and limiting currents from the pair of output amplifiers based upon the at least one programmable output current limit.

Brief Description of the Drawings

FIG. 1 is a schematic block diagram of a subscriber line interface circuit (SLIC) including a transient current limit circuit according to the invention.

FIG. 2 is a schematic block diagram of the transient current limit circuit of FIG. 1.

FIG. 3 is a more detailed schematic diagram of an embodiment of the transient current limit circuit of FIG. 2.

FIG. 4 is a more detailed schematic diagram of the tip and ring amplifiers of FIG. 1.

Detailed Description of the Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

Referring now to the schematic block diagram of FIG. 1, a subscriber line interface circuit (SLIC) **10** according to the invention is connected via a subscriber loop **11** to a telephone **12**. The SLIC **10** includes a pair of tip and ring output amplifiers **13**, **14** for connection to the subscriber loop **11** and a direct current (DC) loop current limit circuit **23** for limiting current on the subscriber loop to a DC current limit. The DC loop current limit circuit **23** establishes the DC current limit when the phone **12** is off-hook. Yet, as noted above, transient events may occur when the phone **12** first goes off-hook or during ringing and loop start, for example. This may cause transient currents that will not be suppressed by the DC loop current limit circuit **23** because it has not yet been engaged.

According to the invention, a transient output current limit circuit **15** may be included in the SLIC **10** to reduce such transient currents. The transient output current limit circuit **15** is illustratively connected to the outputs of the output amplifiers **13, 14** and receives respective currents I_T, I_R therefrom. The transient output current limit circuit **15** has at least one programmable output current limit which may be set externally via an input **18**. The transient output current limit circuit **15** limits currents from the pair of output amplifiers **13, 14** based upon the at least one programmable output current limit.

More specifically, the transient output current limit circuit **15** limits both source and sink currents for each of the output amplifiers **13, 14.** The transient output current limit circuit **15** may generate a source current limit and a sink current limit based upon the at least one programmable current limit. Furthermore, the transient output current limit circuit **15** may generate the sink current limit to be offset a predetermined amount higher than the source current limit. For example, the transient output current limit circuit **15** may use the programmable current limit as the source current limit, and generate the sink current limit to be the predetermined amount higher than the source current limit.

This is done to prevent the output amplifiers **13, 14** from sinking and sourcing at the same time which may otherwise cause undesirable current oscillations on the subscriber loop, as will be appreciated by those of skill the art. The predetermined amount may be less than about 40% higher than the source current limit, and is preferably about 20% higher. Of course, it may

not be necessary to generate different source and sink current limits for all applications, and it should be understood that the same current limit may be used for both sourcing and sinking according to the invention.

Using a single programmable current limit is advantageous in that the user need only program a single current limit and the transient output current limit circuit **15** will generate the source and sink current limits therefrom. Of course, both a programmable sink current limit and a programmable source current limit may be set externally via inputs **19, 20** rather than having the transient output current limit circuit **15** internally generate these limits. Those of skill in the art will appreciate that numerous other alternatives for setting the source and sink current limits are also contemplated by the invention. An example of programming of the current limit will be described further below.

Referring now to FIG. 2, the transient output current limit circuit **15** includes a reference current generator **25** for generating a reference current based upon the programmable output current limit. Of course, as noted above, both source and sink reference currents may be generated by the reference current generator **25** offset by a predetermined value, if desired. The reference current generator **25** may include a temperature stabilized voltage reference source **26** to provide enhanced temperature stability, as will be appreciated by those of skill in the art. Other suitable voltage sources may also be used.

Source and sink comparators **28, 29** compare sensed source and sink output currents for each of the output amplifiers **13, 14** with the reference current, and control the source and sink currents of the output

amplifiers when the reference current is exceeded. Again, separate source and sink reference currents may be used, as illustrated in FIG. 2, in which the source and sink comparators **28, 29** receive the source and sink reference currents via lines **30, 31**, respectively. Source and sink prescalers **32, 33** are connected to the source and sink comparators and sense the source and sink currents for each of the output amplifiers **13, 14.**

The programmable output current limit may be programmed by connecting a programming resistor **27** between a reference voltage (e.g., ground) and the reference current generator **25.** Of course, other suitable programming devices may also be used in accordance with the invention, as will be appreciated by those of skill in the art. Advantageously, the programming resistor **27** may be located externally to the SLIC **10** so that the current limit(s) for a given application may be easily set by the user during installation. Thus, a single SLIC **10** according to the invention may be used in numerous applications by simply programming the desired current limit for the given application.

By way of example, the above described transient output current limit circuit **15** has been incorporated into the HC55185 family of ringing SLICs (RSLICs) and the ISL5586 family of low power ringing SLICs for home gateways, both of which are made by the Intersil Corporation, assignee of the present invention. Further details regarding these SLICs may be found in the HC55185 Data Sheet from the Intersil Corporation, published February 2001, and the ISL5586 Data sheet from the Intersil Corporation, published June 2001, which are both hereby incorporated herein in their entirety by reference. In the HC55185

application, for example, the sink current limit is internally set by the transient output current limit circuit **15** to be 20% higher than the source current limit, which is programmed by the user. The source current limit is determined by the equation

$$R_P = \frac{1780}{I_{SRC}}, \quad (1)$$

where R_P is the programming resistor **27** and I_{SRC} is the source current limit. Thus, to set a source current limit of 50mA, a 35.6kΩ programming resistor **27** would be used. Accordingly, for a 20% offset, the sink current limit will be set by the transient output current limit circuit **15** to be

$$I_{SNK} = 1.20 \times I_{SRC}, \quad (2)$$

where I_{SNK} is the sink current limit. Thus, if the source current limit is set to be 50mA, the sink current limit will be 60mA. Again, numerous other predetermined offsets are possible according to the invention, and the source and sink current limits may alternatively both be set externally to the transient output current limit circuit **15**, as noted above.

Those of skill in the art will be able to program appropriate current limits for the SLIC **10** based upon the various application in which the SLIC is to be used. Generally speaking, it is desirable to make the programable output current limit higher than the DC current limit so that the DC current limit circuit **23** will be able to take over control of the current limiting from the transient output current limit circuit **15** when the phone **12** goes off-hook.

Additionally, typical ringing SLIC circuits detect an off-hook condition during ringing or "ring-trip" by checking for a ringing current threshold. Thus, if the ringing current threshold is higher than the DC current limit in a particular application, it is preferable to have the programmable output current limit be higher than the ringing current threshold as well. Of course, it is desirable to have the programmable output current limit as low as possible to reduce power consumption but without affecting the DC current limit or ring-trip detection functions. Generally speaking, the programmable output current limit may be less than about 50% higher than the DC current limit (or ring current threshold), though other values may also be used according to the invention.

A detailed embodiment of the transient output current limit circuit **15** may be seen in the schematic diagram of FIG. 3. In this embodiment, the transient output current limit circuit **15** includes individual source and sink comparators **28a**, **29a** for the tip amplifier **13** and individual source and sink comparators **28b**, **29b** for the ring amplifier **14**. Associated therewith are respective tip source and sink current prescalers **32a**, **33a** and ring source and sink current prescalers **32b**, **33b**.

More specifically, the tip source comparator **28a** includes transistors QTL13-QTL17, resistors RTL9-RTL10, and diodes DTL2-DTL3. For clarity of explanation, the tip source comparator **28a** may conceptually be divided into a current comparator section including the transistors QTL13-QTL15, QTL17, and the resistor RTL9, and a transconductance stage including the transistor QTL16, resistor RTL10, and

diodes DTL2-STL3. The transconductance stage drives the high impedance node of the tip amplifier **13.**

The tip sink comparator **29a** includes transistors QTL20-QTL24, resistors RTL13-RTL14, diodes DTL4-DTL5, and a capacitor CTL2. The ring source comparator **28b** includes transistors QTL42-QTL46, resistors RTL19-RTL20, and diodes DTL10-DTL11. The ring sink comparator **29b** includes transistors QTL32-QTL36, resistors RTL23-RTL24, diodes DTL12-DTL13, and a capacitor CTL3. The tip sink comparator **29a,** ring source comparator **28b,** and ring sink comparator **29b** may also be conceptually divided into a current comparator section and transconductance stage similar to the tip source comparator **28a,** as will be appreciated by those of skill in the art.

Moreover, the tip source current prescaler **32a** includes transistors QTL18-QTL19 and resistors RTL11-RTL12. The tip sink current prescaler **33a** includes transistors QTL25-QTL29, resistors R0 and RTL15-RTL16, and diodes DTL7 and DTL16. The ring source current prescaler **32b** includes transistors QTL47-QTL48 and resistors RTL21-RTL22. The ring sink current prescaler **33b** includes transistors QTL37-QTL41, resistors R1 and RTL25-RTL26, and diodes DTL15 and DTL19 (Zener). Also, the reference current generator **25** includes QTL1-QTL5, RTL1-RTL2, and a diode DTL1.

The transient output current limit circuit **15** further includes current mirrors **40-42.** The outputs hiz_tip and hiz_ring of the current mirrors **41, 42** are connected to respective high impedance input nodes of the tip and ring amplifiers **13, 14.** Once the sensed source and sink currents exceed the reference current threshold level, the current comparator output drives the transconductance stage to, in turn, drive current

to the high impedance nodes of the output amplifiers **13, 14** via the respective outputs hiz_tip and hiz_ring with the proper polarity to provide negative feedback. This reduces the voltage drive to the load and therefore reduces the output current. As noted above, both sourcing and sinking may be limited. This may be particularly desirable for Class AB type output stages, as will be appreciated by those of skill in the art.

The prescalers **32a, 32b, 33a, 33b** sense the respective sink and source currents by splitting the currents input thereto from the respective output amplifiers **13, 14** using two transistors with parallel base and emitter connections, namely QTL18, QTL19 for the prescaler **32a;** QTL25, QTL26 for the prescaler **33a;** QTL37, QTL38 for the prescaler **33b;** and QTL47, QTL48 for the prescaler **32b.** For each prescaler **32a, 32b, 33a, 33b,** the current will split between the two transistors by the ratio of their respective sizes. Generally, there may be a large device and a small device. The collector of the large device connects to a power supply or ground (i.e., QTL19, QTL26, QTL38, and QTL48). The collector of the small device (i.e., QTL18, QTL25, QTL37, and QTL47) is fed to the respective comparator **28a, 28b, 29a, 29b.** The current flowing into the respective comparator **28a, 28b, 29a, 29b** is thus a precision attenuated replica of the output current from the respective tip or ring amplifier **13, 14.**

The current mirror **40** includes transistors QTL6-QTL8 and resistors RTL3-RTL4. The current mirror **41** includes transistors Q1, Q127 and Q130, and the current mirror **42** similarly includes transistor QTL49-QTL51. Various interconnection circuitry is also included in the transient output current limit circuit

15, such as transistors QTL9-QTL12, QTL30-QTL31, and QTL52-QTL55; resistors RTL5-RTL8 and RTL27; capacitors CTL1 and CTL4; and diodes DTL8-DTL9.

An example of an operational amplifier **43** that may be used for the output amplifiers **13, 14** is shown schematically in FIG. 4. Generally speaking, the amplifier **43** includes a differential input to single ended output amplifier **45** and an output buffer **46**. The output buffer **46** may include output source and sink current sense sections **47, 48** which provide the source and sink current outputs to the transient output current limit circuit **15.** Advantageously, the output source and sink current sense sections **47, 48** may optionally be used to provide additional prescaling, though other amplifiers may also be used in accordance with the present invention that do not provide prescaling.

More specifically, the differential input to single ended output amplifier **45** includes transistors QA0, QA1, QA1A, QA2, QA2A, QA3-QA5, QA7-QA11, QA15-QA16, QA29-30; resistors R-ZERO, RA3-RA4, RA5A-RA5C, RA6A-RA6C, RA7-RA9, and RA23-RA28; capacitor CA2; and diodes DA1, DA2, and D3. Moreover, the output buffer **46** includes transistors QA13-QA14, QA17, QA18A, QA19-QA21, QA22-QA25, QA26-QA27; resistors RA10A, RA11-RA12, RA12A-RA12H, RA13A-RA13J, RA14-RA15, RA16A, RA19, RA20A-RA20B, RA21A-RA21B, RA22; and diodes DA3-DA8. The output source current sense section **47** includes a transistor QA21X and a resistor R12X, while the output sink current sense section **48** includes a transistor QA25X and a resistor R13X.

Of course, those of skill in the art will appreciate that the transient output current limit circuit **15** of the present invention may be used in

numerous applications in addition to SLICs. For example, the transient output current limit circuit **15** is particularly well suited for applications in which precise operational amplifier output current limiting is desired. The circuit described herein may generally used with the output stage of an operational amplifier to limit the current that is driven into a load resistance. More particularly, numerous applications exist in which amplifiers are used to voltage drive low impedance outputs with which the transient output limit circuit **15** may be used, as will be appreciated by those of skill in the art. Other applications for which the transient output current limit circuit **15** may be used include, for example, voltage amplifier circuits.

Thus, the transient output current limit circuit **15** may be more generally used according to the invention for limiting current from an amplifier, for example. The transient output current limit circuit **15** may include a reference current generator **25** for generating at least one reference current based upon at least one programmable output current limit, respective source and sink prescalers **32, 33** for sensing source and sink output currents for the amplifier, and respective source and sink comparators **28, 29** for comparing the sensed source and sink output currents with the reference current, as described above. The operation of such a transient output current limit circuit **15** is similar to that described above and will not be discussed further herein.

A method aspect of the invention is for limiting current on a subscriber loop **11**. The method may include connecting a pair of output amplifiers **13, 14** to the subscriber loop, programming at least one output current limit, and limiting currents from the

pair of output amplifiers based upon the at least one programmable output current limit, as previously described above.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that other modifications and embodiments are intended to be included within the scope of the appended claims.